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**Research Paper**

# Maximizing system productivity and profitability through crop intensification and diversification with rice (*Oryza sativa*)-based cropping systems in acid soils of Assam

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## ABSTRACT

A field experiment was conducted for 6 consecutive years during 2008–09 to 2013–14, at Jorhat, Assam, to study the soil fertility, system productivity and profitability through crop intensification and diversification with rice (*Oryza sativa* L.)-based cropping system under irrigated medium land acid soil situation of Assam. From the pool analysis of data, it was observed that rice-equivalent yield, system productivity and nutrient-use productivity were found to be the highest in winter rice–cabbage [*Brassica oleracea* (L.) greengram [*Vigna radiata* (L.) Wilczek] (REY 17.72 t/ha) sequence, followed by winter rice–chilli (*Capsicum annuum* L.)–blackgram [*Vigna mungo* (L.) Hepper] sequence (REY 14.37 t/ha) among the 8 cropping sequences under study. There were improvements in post harvest physico-chemical properties of soil in different rice-based cropping systems. Significant variation with 34.0, 36.9 and 65.5% increase in available N, $P_2O_5$ and $K_2O$, respectively, were recorded in winter rice–radish (*Raphanus sativus* L.)–French bean–greengram sequences over initial status of soil. Total uptake of nutrients were also the highest of winter rice–radish–French bean–greengram sequence followed by winter rice–knolkhol [*Brassica oleracea* L. convar. acephala (L.) Alef. Var. gongylodes L.]–French bean–cowpea [*Vigna unguiculata* (L.) Walp.] (fodder) sequence. Economic analysis of the systems revealed that the highest gross returns (210.8 × $10^3$₹/ha), net returns (145.1 × $10^3$₹/ha) and benefit: cost ratio (2.21) were recorded in winter rice–cabbage–greengram sequence under irrigated medium land situation of Assam.

***Key words*** **:** Cropping sequences, Economics, Nutrient-use productivity, Rice equivalent yield, System productivity

In the changing agricultural scenario during globalization, agriculture in North-Eastern Region (NER) of India is increasingly facing the challenges for rainfed and irrigated crop production. However, crop diversification shows lot of promise in alleviating these problems through fulfilling the basic needs and regulating farm income, controlling price fluctuation, ensuring balanced food supply, conserving natural resources, reducing the chemical fertilizer and pesticide loads, environmental safety and creating environmental opportunity (Gill and Ahlawat, 2006). Crop diversification has been recognized as an effective strategy for achieving the objectives of food security, nutrition security, income growth, poverty alleviation, employment generation, judicious use of land and water resources, sustainable agricultural development and environmental improvement (Hedge *et al.,* 2003).

Rice in NER India grown in varied ecosystems and the predominant cropping sequences are winter rice–fallow–autumn rice and winter rice–*toria*–fallow, where the diversification index is heavily influenced by rice. Besides, at farmer's level, potential productivity and monetary benefits act as guiding principles while opting for a particular crop/cropping system. This decision with respect to choice of crops and cropping systems are further narrowed down under the influence of several other factors related to infrastructure facilities, socio-economic factor, and technological development.

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Introduction of pulses and oilseed in the system is more beneficial than cereal-cereal sequence (Umarani *et al.*, 1992). In cropping system; inclusion of pulse, oilseed and vegetable is more beneficial than cereals after cereals (Kumpawat, 2001; Raskar and Bhoi, 2001). As it is difficult to replace the rice by any other crop in the rainy season due to soil and climatic condition of NER of India, only option left is during winter (*rabi*) and summer season for intensification and diversification of rice-based cropping system. Therefore, intensification and diversification of cropping system with the proper use of available limited irrigation facility will provide higher yield as well as better net returns under the climatic conditions of Assam. Even life-saving irrigation during the dry spell can be able to boost up productivity as well as net return from a cropping system followed.

Since, information on crop intensification, diversifications and its impact on productivity, profitability and soil sustainability from NER of India is scanty, the present investigation was undertaken for maximizing soil fertility, productivity and profitability through crop intensification and diversification with rice-based cropping systems under medium land irrigated acid soils of Assam .

## MATERIALS AND METHODS

The trial was conducted under All India Co-ordinated Research Project on Integrated Farming System at Assam Agricultural University, Jorhat (26°48'N, 95°50'E, 86.6 m above mean sea-level), Assam during the period from 2008–09 to 2013–14. The aim of the investigation was to increase the system productivity and profitability through crop intensification and diversification with rice-based cropping system in acid soils of Assam under NER of India. Being situated in sub-tropics, the climate of the study site is characterized by hot and wet summer and dry and cool winter with 4 distinct seasons such as pre-monsoon (March–May), monsoon (June-September), post-monsoon (October–November) and winter season (December–February). The average annual rainfall in the area was recorded as 1,900 mm, of which the major amount of about 70% is received during monsoon and 18–27% in the summer season. Mean maximum and minimum annual temperatures were 27.5°C and 17.2°C, respectively, with the lowest temperature in January and the highest in June. In a year, average relative humidity prevails maximum during the summer (80%) and minimum during the winter (60%). The average sunshine hours received during the summer and the winter are 6 and 4 hours/day respectively.

The soil site belongs to Inceptisols. The analysis of initial soil sample of the experimental site revealed that it was sandy loam (coarse sand 6.68%, fine sand 61.43%, silt 15.23% and clay 15.50%), low in available nitrogen (217.3 kg/ha), phosphorus (16.4 kg/ha) and in available potash (66.3 kg/ha). Besides, the initial bulk density of the soil was 1.61 $Mg/m^3$, particle density 2.29 $Mg/m^3$, water-holding capacity 27.2%, aggregate size 0.50 mm, mean weight diameter 1.81%, *p*H 5.69, EC 0.177 dS/m and organic carbon 0.62%.

The experiment was carried out with 8 different cropping sequences, viz. $T_1$, winter rice–fallow–autumn rice; $T_2$, winter rice–toria–fallow; $T_3$, winter rice–cabbage–greengram; $T_4$, winter rice–cauliflower–black gram; $T_5$, winter rice–knolkhol–french bean–cowpea (fodder); $T_6$, winter rice–capsicum–cowpea (fodder); $T_7$, winter rice–chili–blackgram; and $T_8$, winter rice–radish–french bean–green gram, replicating 4 times in 32 plots each having 6m × 5m (=30 $m^2$) dimensions. Out of these cropping sequences, $T_1$ and $T_2$ treatments consist of first and second pre-dominant cropping system of Assam. The fertilizer's doses, date of sowing, cultivars used, planting and date of harvesting of the crops are presented in Table 1.

Six years average annual rainfall and number of rainy days were recorded as 2,310 mm and 265 days respectively. Winter rice did not require any irrigation throughout the growing period under the climatic situation of Assam. In case of autumn rice, 1 irrigation with 6 cm depth was provided at the time of puddling and subsequently 4 numbers of irrigations with 4 cm depth were provided during different growth stages. Besides, 4 irrigations of 4 cm depth were provided to chili, 3 to cabbage, 2 to cauliflower, knolkhol and french bean. For *toria* crop, only 1 irrigation (of 4 cm depth) was given at the time of flowering. One irrigation (of 2 cm depth) was provided to summer greengram and blackgram before sowing and subsequently, another irrigation (of 2 cm depth) was given 15 days after germination due to dry weather conditions. Cowpea (fodder) was irrigated with only 2 cm depth of irrigation 20 days after germination. Intercultural operations for all these crops were performed as per recommended package and practices of the region.

During the study observation on grain and straw/stover/head/fodder yield of different crops were recorded; and rice-equivalent yield (REY), economic viability and system productivity (SP) were calculated by standard methods. SP (yield per unit area per unit time) was calculated to identify the efficient cropping systems. The REY of the systems were calculated in terms of winter rice using the following formula:

$$REY = \Sigma\, Yi \times Pi / P(p)$$

where, Yi= yield of different crops; Pi= price of respective crops and P(p)= price of rice.

Soil samples were collected every year from effective root-zone depth (0–30 cm) after harvesting of the last crop of the systems from each plot and were air-dried, pro-

**Table 1.** Doses of fertilizers, date of sowing, cultivers used, planting and harvesting of the crops

| Treatment | Fertilizer (N-P-K kg/ha) | | | Date of sowing in seed bed | | | Cultivars used for the crops | | | Date of planting/sowing in main field | | | Date of harvesting | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Kharif* | *Rabi* | *Summer* | *Kharif* | *Rabi* | *Summer* | *Kharif* | *Rabi* | *Summer* | *Kharif* | *Rabi* | *Summer* | *Kharif* | *Rabi* | *Summer* |
| $T_1$ | 80–40–40 | – | 80-40-40 | 2 June 2010 | 2 June 2010 | 2 Mar 2011 | Winter rice (Rajendra Suwasini)* | Fallow | Autumn rice 'Disang' | 30 June 2010 | - | 1 Jan 2011 | 07 Oct 2011 | - | 20 Jun 2011 |
| $T_2$ | 80–40–40 | 60–40–40 | – | 2 June 2010 | – | – | Winter rice (Rajendra Suwasini)* | Toria 'TS 38' | Fallow | 30 June 2010 | 5 Nov 2010 | - | 07 Oct 2011 | 08 Feb 2011 | - |
| $T_3$ | 80–40–40 | 120–60–60 | 15–35–10 | 2 June 2010 | 30 Sep 2010 | - | Winter rice (Rajendra Suwasini)* | Cabbage 'Golden Acre' | Green gram 'Pratap' | 30 June 2010 | 5 Nov 2010 | 15 Mar 2011 | 07 Oct 2011 | 13 Jan 2011 | 01 Jun 2011 |
| $T_4$ | 80–40–40 | 80–60–60 | 15–35–10 | 2 June 2010 | 30 Sep 2010 | - | Winter rice (Rajendra Suwasini)* | Cauliflower 'Pusa Snowball' | Black gram 'PU-31' | 30 June 2010 | 5 Nov 2010 | 15 Mar 2011 | 07 Oct 2011 | 20 Dec 2010 | 20 May 2011 |
| $T_5$ | 80–40–40 | 80–60–60 | 20–40–20 30–40–20 | 2 June 2010 | 30 Sep 2010 | - | Winter rice (Rajendra Suwasini)* | Knolkhol 'White Vienna' – French bean 'Anupam' | Cowpea (Fodder) 'EC 4216' | 30 June 2010 | 5 Nov 2010 7 Jan 2010 | 20 Mar 2011 | 07 Oct 2011 | 17 Dec 2010 20 Feb 2011 | 15 May 2011 |
| $T_6$ | 80–40–40 | 120–60–60 | 20–40–20 | 2 June 2010 | 17–10–10 | - | Winter rice (Rajendra Suwasini)* | Capsicum ' 'California Wonder | Cowpea (Fodder) 'EC 4216' | 30 June 2010 | 15 Nov 2010 | 25 Mar 2011 | 07 Oct 2011 | 27 Feb 2011 | 15 May 2011 |
| $T_7$ | 80–40–40 | 120–60–60 | 15–35–10 | 2 June 2010 | 30 Sep 2010 | - | Winter rice (Rajendra Suwasini)* | Chilli 'Namdhari' | Black gram 'PU 31' | 30 June 2010 | 15 Nov 2010 | 15 Mar 2011 | 07 Oct 2011 | 17 Feb 2011 | 19 May 2011 |
| $T_8$ | 80–40–40 | 50–100–100 30–40–20 | 15–35–10 | 2 June 2010 | 30 Sep 2010 | - | Winter rice (Rajendra Suwasini)* | Radish 'Pusa Chetki' French bean 'Anupam' | Green gram 'Pratap' | 30 June 2010 | 5 Nov 2010 7 Jan 2011 | 15 Mar 2011 | 07 Oct 2011 | 19 Dec 2010 17 Feb 2011 | 01 Jun 2011 |

$T_1$, Winter rice–fallow–autumn rice; $T_2$, winter rice–*toria*–fallow; $T_3$, winter rice–cabbage–greengram; $T_4$, winter rice–cauliflower–blackgram; $T_5$, winter rice–knolkhol– french bean–cowpea (fodder); $T_6$, winter rice–capsicum–cowpea (fodder); $T_7$, winter rice–chilli–blackgram; $T_8$, winter rice–radish–french bean–greengram cessed to pass through a 2-mm sieve and stored in polythene bags. Physico-chemical properties of soil were analysed using the internationally accepted methods referring the methods of Jackson (1973) and Baruah and Borthakur (1997). Apparent nutrient-use productivity (ANUP) was calculated dividing the equivalent yield of the system by the total quantity of nutrients used. Land-use efficiency (LUE) was calculated using the following method and it refers to the extent of land area used in a year.

LUE (%) = TND(i) × 100/ 365

where TND(i) denotes total number of days field remained occupied under different crops (i = 1 n).

Economics of the systems were calculated on the basis of the prevailing market prices of the commodities during the study. All data were subjected to the analysis of variance (ANOVA) appropriate to the design using the windows-based statistical package for the social science (SPSS 2001). Test of significance of the treatment difference was done on the basis of the *f*-test (Gomez and Gomez, 1984). The least significant differences (LSD) between the treatments were compared at 5% level of probability.

## RESULTS AND DISCUSSION

### *Yield of crops*

The average yields of main products and by-products of different crops as well as the average rice-equivalent yield (REY) from 2008–09 to 2013–14 under different rice-based cropping sequences are presented in Table 2. Different rice-based cropping systems significantly influenced the REY of crops. The average REY after the 6 cycles of crops ranged between 5.01 and 17.72 t/ha. Significantly the highest REY was recorded in winter rice–cabbage–greengram sequences, followed by winter rice–chili–blackgram as compared to the other cropping sequences. Winter rice–cabbage–greengram sequences showed 254.0 and 232.0% increase in REY, respectively, over the prevailing first (winter rice–fallow–autumn rice with REY 5.01 t/ha) and second (winter rice–*toria*–fallow with REY 5.34 t/ha) pre-dominant cropping system of Assom. This was due to the fact that higher yield (23.9 t/ha) was obtained with cabbage along with the relatively better price of the produce (₹10.0/kg). Similar results were also reported by Baishya *et al.* (2013).

### *System productivity, nutrient-use productivity and water productivity*

The effect of different rice-based cropping sequences on system productivity (SP), nutrient-use productivity (NUP) and water productivity (WP) are presented in Table 2. Data showed that the effect on system productivity was significant with the highest value in winter rice–cabbage–greengram, followed by winter rice–chili–blackgram sequence (Table 2).

Nutrient-use productivity (NUP) varied from 20.9 to 35.1 kg/ha/kg nutrient applied and significantly the highest NUP was recorded in winter rice–cabbage–greengram sequence. The lowest SP and NUP were found in winter rice–fallow–autumn rice, followed by winter rice–*toria*–

**Table 2.** Average yield of crops, rice-equivalent yield (REY), system productivity (SP) and nutrient-use productivity (NUP) of rice-based sequences (data given are mean value of 6 years from 2008–09 to 2013–14)

| Cropping sequence | Yield of *kharif* crop(t/ha) | | Yield of *rabi* crop(t/ha) | | Yield of summer crop(t/ha) | | REY (t/ha) | System productivity (kg/ha/day) | Nutrient-use productivity (kg/ha/kg nutrient applied) | Water productivity (kg/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Main produce* | By-product** | Main produce* | By-product** | Main produce* | By-product** | | | | |
| Winter rice–fallow–autumn rice | 3.30 | 9.93 | - | - | 6.72 | 9.07 | 5.01 | 14.00 | 20.88 | 2.28 |
| Winter rice–*toria*–fallow | 3.63 | 10.9 | 1.49 | 2.17 | - | - | 5.34 | 15.00 | 21.38 | 13.36 |
| Winter rice–cabbage–Greengram | 3.47 | 11.5 | 23.9 | 12.3 | 0.96 | 3.99 | 17.7 | 49.00 | 35.10 | 11.08 |
| Winter rice–cauliflower–blackgram | 2.80 | 8.43 | 7.52 | 8.77 | 1.13 | 5.07 | 10.4 | 29.00 | 25.70 | 8.69 |
| Winter rice–Knolkhol–French bean–cowpea (Fodder) | 3.57 | 11.2 | 5.48-7.28 | 3.86- 9.19 | 9.93 | 9.93 | 12.3 | 34.00 | 24.79 | 6.83 |
| Winter rice–capsicum–cowpea (Fodder) | 3.17 | 9.73 | 2.19 | 2.40 | 12.8 | 12.8 | 12.2 | 33.00 | 27.34 | 6.78 |
| Winter rice–chilli–blackgram | 3.13 | 9.67 | 2.80 | 3.00 | 1.22 | 5.10 | 14.4 | 39.00 | 32.31 | 7.19 |
| Winter rice–radish–french bean–greengram | 3.13 | 9.97 | 21.0-5.06 | 11.5-7.08 | 0.81 | 3.45 | 14.0 | 38.00 | 23.65 | 11.65 |
| SEm± | - | - | - | - | - | - | 0.41 | 1.96 | 1.09 | 3.10 |
| CD (*P*=0.05) | - | - | - | - | - | - | 1.29 | 6.07 | 5.00 | 8.23 |

*Major produce for which crop was grown, e.g. grain/seed/pods/head yield/green cobs/green fodder/fruits/green leaves etc.

**By-products such as straw/stover/green fodder etc.

fallow sequences, which were first and second pre-dominant cropping system of Assam. This was owing to high yield as well as better price obtained from vegetable crops. These results confirm the findings of Singh *et al*. (2010).

The highest water productivity (WP) was recorded in winter rice–*toria*–fallow (Table 2) which may owing to lowest amount of water applied to this sequence (400 $m^3$/ha), because rainfall received during the *kharif* season was enough for which no irrigated water was applied in winter rice and water requirement of *toria* is very less under Assam condition if it is sown in proper time followed by the winter rice–radish–french bean–greengram and winter rice–cabbage–greengram sequences (Table 2). The lowest water productivity was calculated for the winter rice–fallow–autumn rice sequence, which may be due to highest amount of water applied to the autumn rice (2,200 $m^3$/ha).

### *Employment generation*

Employment generation in different rice-based cropping systems under irrigated condition in Assam is illustrated in Fig. 1. The employment generation was the highest (307 man-days/ha) with winter rice–chilli–blackgram sequence which was at par with winter rice–knolkhol–frenchbean–cowpea (fodder) sequence (306 man-days/ha). This may be attributed to more man-power requirement for intercultural operations with chilli, knolkhol and french bean during the winter (*rabi*) season (Baishya *et al*., 2013). The winter rice–*toria*–fallow sequence exhibited the lowest employment generation followed by winter rice–fallow–autumn rice.

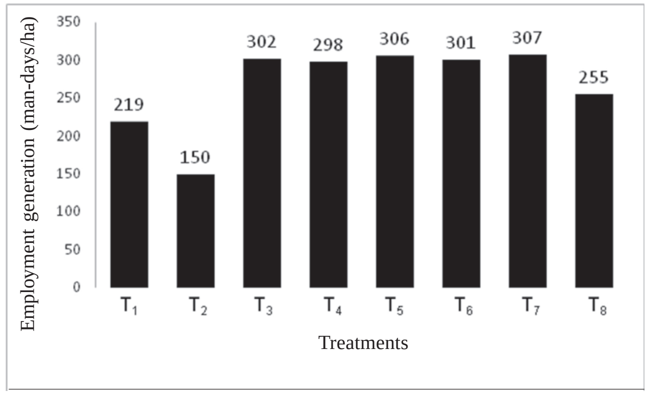


**Fig. 1**. Employment generation in case of different rice-based cropping system in Assam situation

$T_1$, Winter rice–fallow–autumn rice; $T_2$, winter rice–*toria*–fallow; $T_3$, winter rice–cabbage–greengram; $T_4$, winter rice–cauliflower–blackgram; $T_5$, winter rice–knolkhol–french bean–cowpea (fodder); $T_6$, winter rice–capsicum–cowpea (fodder); $T_7$, winter rice–chilli–blackgram; $T_8$, winter rice–radish–french bean–greengram

### *Physico-chemical properties of soil*

The post-harvest physico-chemical properties (average of 6 years) of soil in different rice-based cropping systems in acid soils of Assam revealed that the variation in bulk density of soil was significant and ranged from 1.43 to 1.60 Mg/$m^3$ (Table 3). The lowest bulk density was recorded from winter rice–radish–french bean–greengram sequence, whereas the highest in winter rice–chilli–blackgram sequence. Different rice-based cropping system produced a significant effect on soil aggregate size, which ranged between 0.52 and 0.71 mm. There were 12.7 and 16.4% increase in soil aggregate sizes in winter rice–knolkhol–frenchbean–cowpea (fodder) sequence, respectively, over the first and second most prevailent pre-dominant cropping system of Assam. All the treatments showed

**Table 3.** Post harvest physico-chemical properties and nutrient status of soil under rice-based cropping systems

| *Treatment* | Bulk density (Mg/$m^3$) | Aggregate size (mm) | Water-holding capacity (%) | *p*H | Electrical conductivity (dS/ m) | Soil organic carbon (mg/kg) | Available primary nutrients (kg/ha) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | N | P | K |
| $T_1$ | 1.56 | 0.63 | 31.7 | 5.71 | 0.243 | 6366 | 250.5 | 17.3 | 84.0 |
| $T_2$ | 1.57 | 0.61 | 29.7 | 5.67 | 0.223 | 6266 | 284.1 | 16.6 | 86.0 |
| $T_3$ | 1.45 | 0.69 | 32.0 | 5.65 | 0.213 | 6910 | 270.5 | 19.0 | 90.8 |
| $T_4$ | 1.51 | 0.68 | 31.3 | 5.69 | 0.237 | 6866 | 273.0 | 19.5 | 94.0 |
| $T_5$ | 1.44 | 0.71 | 31.4 | 5.77 | 0.250 | 7100 | 277.1 | 20.3 | 96.4 |
| $T_6$ | 1.57 | 0.52 | 31.8 | 5.64 | 0.207 | 5133 | 272.7 | 19.5 | 92.4 |
| $T_7$ | 1.60 | 0.58 | 30.7 | 5.60 | 0.187 | 5766 | 262.5 | 19.5 | 96.5 |
| $T_8$ | 1.43 | 0.70 | 33.7 | 5.68 | 0.233 | 7166 | 291.0 | 22.5 | 109.8 |
| Initial value | 1.61 | 0.50 | 27.2 | 5.69 | 0.177 | 6200 | 217.3 | 16.4 | 66.3 |
| SEm± | 0.010 | 0.002 | 0.65 | 0.003 | 0.003 | 66.2 | 2.17 | 0.11 | 1.12 |
| CD ($P$=0.05) | 0.028 | 0.009 | 1.36 | 0.011 | 0.009 | 179.7 | 6.36 | 0.40 | 5.43 |

$T_1$, Winter rice–fallow–autumn rice; $T_2$, winter rice–*toria*–fallow; $T_3$, winter rice–cabbage–greengram; $T_4$, winter rice–cauliflower–blackgram; $T_5$, winter rice–knolkhol– french bean–cowpea (fodder); $T_6$, winter rice–capsicum–cowpea (fodder); $T_7$, winter rice–chilli–blackgram; $T_8$, winter rice–radish–french bean–greengram an increase in water-holding capacity (WHC) of soil. The highest WHC was from winter rice–radish–frenchbean–greengram sequence, which showed 24.0% increase over initial status of soil. However, the lowest WHC of soil was recorded in winter rice–*toria*–fallow sequence (Table 3).

The effect of different rice-based cropping sequences on soil pH and electrical conductivity (EC) after the harvesting of the crops was non-significant (Table 3). Winter rice–knolkhol–french bean–cowpea (fodder) sequence revealed the highest *p*H and EC of soil, whereas the lowest from winter rice–chilli–blackgram sequence.

Different rice-based cropping systems significantly affected the soil organic carbon (SOC) content that ranged from 5,133–7,166 mg/kg. The highest SOC content was recorded under winter rice–radish–frenchbean–greengram ($T_8$) followed by winter rice–knolkhol–frenchbean–fodder cowpea ($T_5$) sequence. Maximum increase in SOC content of soil 15.6 and 15.5%, respectively, were recorded from $T_8$ and $T_5$ treatment. Such increase in SOC might be owing to more number of crops included in the system resulting in higher root and shoot biomass production (Baishya *et al*., 2013).

### *Primary nutrients status of the soil*

All the available primary nutrients in soil were significantly affected by different rice-based cropping sequences (Table 3). This might be due to inclusion of different crops including pulses in the sequences. The available N in soil was varied from 250.5 to 291.0 kg/ha. Winter rice–radish–french bean–greengram sequence showed the maximum 33.9% increase in available N in soil over initial. Palaniappan and Sivaraman (1994) and Saha and Moharana (2007) who emphasized that rice–pulse system was effective for higher amount of available N, P-$_2O_5$ and $K_2O$. Pulse crops with their characteristic promotion of free-living microorganisms (*Rhizobium* spp.) release N in soil. Release of N helps narrowing down of C : N ratio and thus, increased mineralization resulted in rapid conversion of organically bound N to inorganic forms (Singh *et al.,* 2006; Gogoi *et al.,* 2015).

The highest available $P_2O_5$ in soil was recorded in winter rice–radish–frenchbean–greengram sequence, which was 36.9% higher than the amount recorded at initial stage. This favourable effect of multiple cropping (including 2 crops of legumes in the sequence) in enhancing the P availability may be attributed to the reduction in fixation of water-soluble P and increase in mineralization of P due to microbial action which enhanced the availability of P. The organic anions and hydroxyl acids liberated during the crop-growth period may complex or chelate Fe, Al, Mg and Ca and prevent them from reacting with phosphate (Sharma *et al.,* 2001; Gogoi, 2011).

Available $K_2O$ after harvesting of different rice-based cropping sequences indicated an improvement over initial status. The maximum $K_2O$ availability was recorded from winter rice–radish–french bean–greengram, followed by winter rice–knolkhol–french bean–cowpea (fodder) sequence. Significantly lowest availability of $K_2O$ was re-

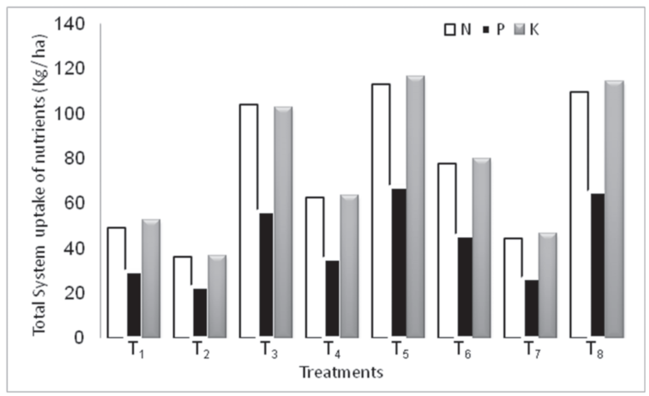


**Fig. 2**. Total system uptake of nutrients in different rice-based cropping systems

$T_1$, Winter rice–fallow–autumn rice; $T_2$, winter rice–*toria*–fallow; $T_3$, winter rice–cabbage–greengram; $T_4$, winter rice–cauliflower–blackgram; $T_5$, winter rice–knolkhol–french bean–cowpea (fodder); $T_6$, winter rice–capsicum–cowpea (fodder); $T_7$, winter rice–chilli–blackgram; $T_8$, winter rice–radish–french bean–greengram

**Table 4.** Economics of rice-based cropping systems

| Cropping sequences | Cost of cultivation (×10³ ₹/ha) | Net returns (×10³ ₹/ha) | Benefit: cost ratio |
|---|---|---|---|
| Winter rice–fallow–autumn rice | 39.8 | 23.7 | 0.60 |
| Winter rice–toria–fallow | 29.7 | 36.2 | 1.22 |
| Winter rice–cabbage–greengram | 65.7 | 145.1 | 2.21 |
| Winter rice–cauliflower–blackgram | 56.5 | 67.4 | 1.20 |
| Winter rice–knolkhol–french bean–cowpea (fodder) | 70.2 | 83.1 | 1.19 |
| Winter rice–capsicum–cowpea (fodder) | 65.6 | 76.8 | 1.17 |
| Winter rice–chilli–blackgram | 59.3 | 111.4 | 1.88 |
| Winter rice–radish–french bean–greengram | 65.6 | 102.4 | 1.56 |
| SEm± | - | 5.05 | 0.05 |
| CD (P=0.05) | - | 13.0 | 1.00 |

corded in winter rice–fallow–autumn rice sequence. Similar results were also reported by Baishya *et al*. (2013) under irrigated medium land situation of Assam.

### *Nutrient uptake*

Total NPK uptake by the cropping systems is depicted in the Fig. 2, showed that total uptake of nutrients was the highest in winter rice–radish–frenchbean–greengram sequence, followed by winter rice–knolkhol–french bean–cowpea (fodder) sequence. Higher uptake by the sequence may be attributed to greater biomass production, as also reported by Sharma *et al.,* (2008). Baishya *et al.* (2013) also observed higher uptake of NPK in case of 4 crop sequence as compared to 3-and 2-crop sequences in acid soils of Asom. Among all the rice-based cropping systems, winter rice–*toria*–fallow showed the lowest total system uptake of NPK which was immediately followed by winter rice–chili–blackgram system.

### *Economics*

The gross returns, net returns and benefit: cost ratio were affected by rice-based cropping systems (Table 4). The highest gross returns, net returns and benefit: cost ratio were recorded in case of winter rice–cabbage–greengram sequence. This might be owing to higher production of cabbage in this sequence. This was followed by winter rice–chili–blackgram sequence with the benefit: cost ratio of 1.88, which might be attributed to higher production and more remunerative price of chili. Among the 8 sequences, the minimum benefit: cost ratio was observed with winter rice–fallow–autumn rice sequence under the irrigated medium land acid soil situation of Asom.

Based on 6 years findings of this experiment it can be concluded that under irrigated conditions of Asom of North-Eastern Region of India, winter rice–cabbage–greengram followed by winter rice–chili–blackgram cropping systems were found more productive, resource-use efficient and remunerative. If there is fall in market price of crops like cabbage, cauliflower etc., farmers can shift to other crops like chili, radish, french bean etc. during the winter (*rabi*) season. Inclusion of pulses in the cropping sequences improved the soil properties as compared to winter rice–fallow–autumn rice and winter rice–*toria*–fallow sequences in the acids soils of Asom. Hence under Asom condition the existing pre-dominant cropping system can be profitably intensified and diversified by maintaining/improving natural resources.

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